Instantaneous field of view and pixel size along track in pushbroom cameras

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1. Suggestion for the standard

The current version of the standard says that, for a pushbroom camera, the projection of the slit width onto the scene is the instantaneous field of view (iFOV), and that the projection of the slit width:

1. Directly affects the amount of light that the camera sensor receives,
2. Is equal to the width of the area that the camera sees in the along track direction at a given moment in time,
3. Is equal to the pixel size in the along track direction.

The current version of the standard does not recognize that (1), (2), and (3) are three different things which are almost always different from each other in a given camera. And, while (1) is correct, (2) and (3) are not.

Standard should reflect that, for a pushbroom camera, iFOV is not the same for radiometry and for the spatial specs. Also, the standard should reflect that pixel size along track is not the same as either of the two iFOVs mentioned above. NEO's suggestion for the standard is:

1. **iFOV for radiometry is determined by the projection of the slit width onto the scene** (this is the same as in the current version of the standard)**.**
2. **iFOV for spatial (what objects are visible to the camera at a given moment in time) is determined by SPSF FWHM (by its robust equivalent) in the along track direction.**
3. **For a single frame, pixel size in the along track direction is undefined (because pixel size is defined from pixel pitch, cross-track pixel size being an example of this approach). When quantifying spatial specifications of a camera (such as SPSF FWHM in the along track direction), pixel size in the along track direction is assumed to be the same as in the cross-track direction, unless explicitly specified otherwise by the camera manufacturer.**

2. Benefits of this approach

a. Slit width, being a design parameter that may be just a minor contributor to the along track iFOV, no longer defines pixel size in the camera specs. This allows the designer to optimize the slit width for the optimum combination of light throughput, spatial resolution, and spectral resolution without affecting the formal "pixel size" specification on the camera's spec sheet.
b. For spatial iFOV, the literal meaning of the term now corresponds to what the term attempts to define: (spatial) instantaneous field of view is what camera sees in the along track direction at a given moment in time.
c. Some discrepancies in specifications with other camera types are removed.
d. Some discrepancies between the pixel size definitions for along- and cross-track directions are removed.

3. Explanation and comments

3.1. Instantaneous field of view

In a pushbroom hyperspectral camera, the slit is a field stop. However, unlike typical field stops in most imaging systems, the slit has a very small width (the dimension in the along track direction). Because of the small width of the slit, the area of the scene that is visible to the camera in the along track direction, may be heavily affected by the PSF of the camera foreoptics. If the PSF is wide enough, it may even be the major contributor to what the camera sees in the along track direction. Therefore, it is incorrect to use the slit width alone for defining the spatial iFOV.

Let us consider the two examples shown in Fig.1. The upper example is a camera with a wide slit (the slit width = A, shown with dashed lines) and a narrow PSF of the foreoptics (shown in green). The lower example is a camera with a narrow slit (the slit width = B) and a wide PSF of the foreoptics.

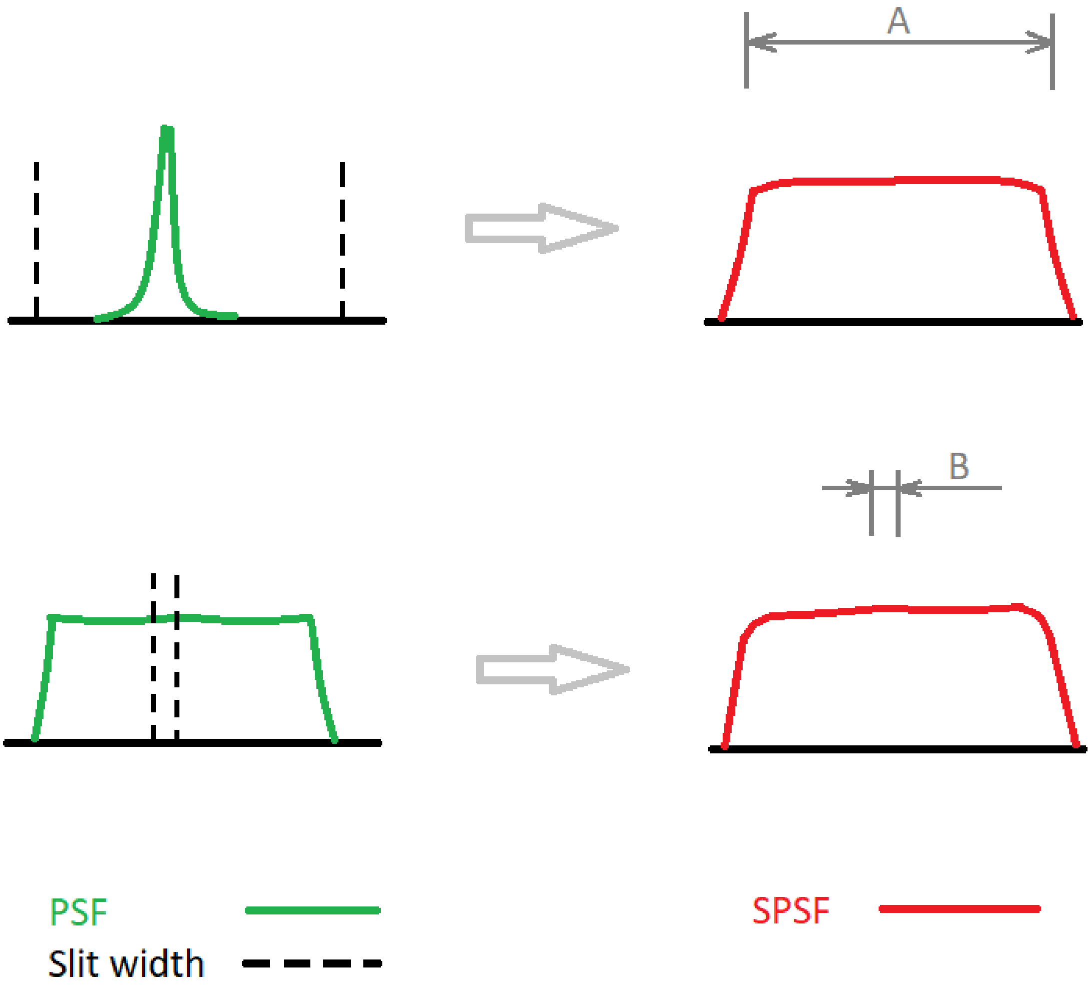

Fig.1. Two pushbroom cameras that have nearly identical SPSFs in the along-track direction: (top) a camera with a wide slit A and a narrow PSF, (bottom) a camera with a narrow slit B and a wide PSF.

Note that in these two examples, SPSFs of the two cameras (red curves), i.e., what each camera sees in the along track direction, are more or less identical, while the slit widths (and therefore the iFOVs, according to the current version of the standard) are ten times(!) different. These two examples clearly demonstrate the discrepancy between iFOV definition in the current version of the standard and the actual field of view that a camera has in the along track direction.

The correct specification for the iFOV (in the context of spatial specifications) would be the SPSF width (SPSF FWHM) in the along track direction. This approach is justified by the very definition of SPSF: it is the sensitivity of an imaging element as a function of a coordinate – so SPSF width is the FOV of an imaging element.

3.2. Pixel size in the along track direction

The current version of the standard defines cross-track pixel size from pixel pitch. This approach is logical and can be illustrated by the three examples in Fig.2. These are 3 different one-dimensional pixel arrays that are expected to operate in the pushbroom mode. The 3 arrays have the same pixel pitch A, but different fill-factors (the light-sensitive area of each pixel is filled with black colour). Note that for the pixel arrays with small fill-factors (the examples in the middle and in the bottom of Fig.2) cross-track pixel size B is not defined by the size of the light-sensitive area – B remains the same for all three arrays. Also note that for the two arrays with smaller fill-factor, the only clue about pixel size is the pixel pitch.

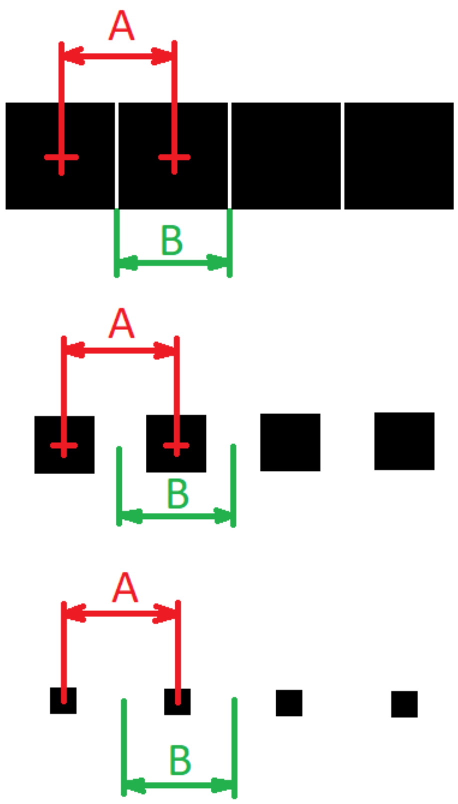

Fig.2. Three one-dimensional pixel arrays with the same pixel pitch A and different fill-factors. Light-sensitive area of each pixel is filled with black colour. Cross-track pixel size B is defined to be equal to pixel pitch A.

However, for the along track direction, when only considering a single frame, the pixel pitch is not defined – because at least two pixels are needed for defining it. The pixel pitch for that direction will be formed and recorded to the image only when more than one frame is acquired, i.e., the pixel pitch will be defined in the acquired image. Saying that pixel pitch in the along track direction is shrinking together with the size of the light-sensitive area (while, at the same time, saying that the cross-track pixel size is not shrinking with the size of the light sensitive area) is not correct (and not logical). Just like for the cross-track direction where the pixel pitch is not connected to the size of the light-sensitive area, for the along track direction the pixel pitch is not connected to the size of that area either.

Let us apply the same logic to a pushbroom hyperspectral camera where the size of the light-sensitive area in the along track direction is the slit width (instead of the height of the light-sensitive area of a pixel in Fig.2). When the slit width changes, the pixel pitch (and therefore pixel size) in the along track direction does not need to change – just like the cross-track pixel pitch does not change with a different pixel fill-factor.

Saying that the pixel size in the along track direction has to be the same as SPSF FWHM in that direction, is not right either. Let us again compare the reasoning with the cross-track direction. SPSF width there clearly does not affect the pixel pitch: you can have a very large SPSF FWHM or nearly a pixel-sized one – the pixel pitch (and pixel size) remains the same.

So, what along track pixel pitch (and therefore pixel size) should we assume when deriving camera specifications? In many (perhaps in most?) cases, it is expected to have square pixels in the hyperspectral datacube. This means that the pixel pitch in the along track direction is the same as in the cross-track direction. If we postulate that, then we can specify items like SPSF FWHM in the along track direction in pixel units, and the optical performance in the along- and cross-track directions can be easily compared – because the units (pixel dimensions) are the same.

Since some cameras are intended to operate differently, the standard shall accommodate that. Some cameras need to have longer integration time (to collect enough light or to accommodate a slower sensor) than what would be required for keeping the pixel shape squared, other cameras improve the optical performance in the along-track direction by keeping the integration time shorter – again, the pixels become rectangular. If the camera manufacturer intends the camera to acquire rectangular pixels, the standard shall allow for specifying non-square pixel sizes (see Chapter 1 for the recommended formulation).

4. Conclusion

This approach of specifying iFOV and along track pixel size is based on the process of image formation in a pushbroom hyperspectral camera. Most importantly, this approach does not impose artificial restrictions on the internal camera design parameters for meeting the desired pixel size specifications.